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Book Reviews

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Irreversible Phenomena: Ignitions, Combustion and Detonation Waves

Kunio Terao, Springer, New York, 2007, 409 pp. $189

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A broad range of combustion phenomena occur that exhibit inherently stochastic behavior, producing fascinating observations but also significant challenges in experiments, simulations, and predictive models. Although the turbulence and turbulent combustion literature is rich in statistical modeling approaches (for example, texts by Pope [1] or Peters [2], among many others), the stochastic nature of ignition processes, shock-induced combustion, and detonation waves has been much less comprehensively addressed. This book is focused on the latter applications and offers a rather unique viewpoint in comparison with the existing combustion literature.

The author presents a discussion of combustion theory from his perspective, based on the compilation of an extremely broad range of experimental results obtained by the author or his coworkers over a span of some 40 years. As discussed in the introduction, the author considers that inherently irreversible processes (such as ignition, combustion, and detonation events that exhibit a significant entropy increase and proceed with finite velocity) cannot be modeled even approximately using mathematical descriptions based on the first law of thermodynamics. Instead, the author proceeds from a discussion of the second law of thermodynamics with applications to fluctuating phenomena experimentally observed in ignition events, combustion, and detonation waves.

The introduction, Chapter 1, presents a brief summary of the author's ideas and theory for the book. Whether or not one agrees with the limitations of first-law-based theories in predicting ignition and combustion phenomena, the broader philosophy behind Terao's argument is clearly set out and an excellent basis for discussion is provided. Classical ignition theories are briefly given in Chapter 2 and contrasted with a stochastic theory for irreversible phenomena presented in Chapter 3. Chapter 3 contains the core theory around which the book is based and opens with a discussion of reversible and irreversible processes. Fluctuating phenomena are argued to appear due to a heterogeneous and nonequilibrium minimum entropy state and to be governed by a probability distribution. Beginning with the second law of thermodynamics, a model relating ignition and development to occurrence probability is developed and subsequently applied in the remainder of the text to fluctuating phenomena observed in irreversible events.

The next chapters deal with the concept of heterogeneity in ignition problems, although the first application of Terao's theory is to nucleation theory in phase transition (Chapter 4). Then, after a standard introduction to shock waves and shock tubes in Chapter 5, applications and observations pertaining to ignition processes are discussed extensively in Chapters 6–8, including shock-induced ignition, ignition in a fuel spray, and spark ignition. These chapters provide data that serve as the most direct test of the author's hypothesis for ignition problems. Experiments measuring fluctuations in induction time and ignition location are described, and ignition probabilities are calculated from the resultant histograms. The application of Terao's stochastic theory to explosion limits is treated in Chapter 6, together with a discussion on reaction mechanisms that would have been enhanced by more extensive referencing of the existing literature. Chapter 6 concludes with a point-by-point comparison of classical ignition theory based on chain-branching kinetics and the author's heterogeneous stochastic ignition theory.

The appearance of a nonequilibrium state in flames and detonations is discussed in Chapter 9. Several experimental techniques used in measuring the relevant temperatures are described, together with a summary of results from the author's work. A rather extensive presentation of an adiabatic flame temperature calculation is included. Combustion events and flame propagation measurements are treated in Chapter 10. Because the emphasis of the current book is fluctuating phenomena in ignition processes, high-temperature effects in flames, and detonation waves, turbulent combustion reasonably receives very limited attention.

Gaseous detonation waves are discussed in Chapter 11. An introduction to steady-state detonation theory that begins the chapter follows other available texts because the material is standard, although the Chapman–Jouguet condition is usually given more prominence. Cellular structure and soot foil measurements are discussed, providing a clear illustration of the stochastic nature of detonation waves. Results from experiments, many of them unique, on detonation initiation (shock-induced and deflagration-to-detonation transition), shock–detonation interaction, detonation propagation as a function of initial mixture temperatures, and gas ionization behind detonation waves are given. Finally, some interesting experiments investigating imploding shock and detonation waves are described in Chapter 12.

There are a few typographical errors in the text and figures and some linguistic difficulties that escaped the editorial process; however, the central argument of the book and the subsequent applications are clearly laid out and discussed, resulting in a very interesting read. A weakness of the current text that could be corrected in future editions is that error bars from the original experiments are occasionally omitted. Because the focus is on examining fluctuating phenomena that are "quite different from the experimental error" and testing the hypothesis that observed fluctuations are governed by the probability theory developed in the text, an analysis of the sources and magnitudes of experimental errors would have greatly strengthened the discussion.

The book provides valuable access to numerous experimental and theoretical results less readily available in the English literature. A broad range of relevant experimental results by the author and coworkers are described throughout the book, ranging from investigations of ignition probability in a fuel spray to ionization in detonation waves. References to other texts are intentionally limited and are used mainly to illustrate differences between classical theories and the author's approach. This book should be considered a specialist rather than a general graduate-student-level text, in that it presents a unique viewpoint and selected results rather than a general overview of current theory. Instead, the book fulfills its intended purpose and comprehensively presents the author's and coworkers' body of work and theory of irreversible combustion phenomena.

References

[1] Pope, S. B., *Turbulent Flows*, Cambridge Univ. Press, New York, 2000.

[2] Peters, N., *Turbulent Combustion*, Cambridge Univ. Press, New York, 2000.

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